REMARKS

Claims 1-37 are now pending in the application. The Examiner allowed Claims 1-8 subject to correction under 37 C.F.R. 1.75(a). Claims 10, 17, 25, 32, and 33 were canceled without prejudice. Minor amendments have been made to the specification and claims to simply overcome the objections to the specification and rejections of the claims under 35 U.S.C. § 112. The Examiner is respectfully requested to reconsider and withdraw the rejections in view of the amendments and remarks contained herein.

OBJECTION TO THE DRAWINGS

The Examiner objected to the drawings under 37 C.F.R. 1.83(a) for failing to show every feature of the invention specified in the claims.

Applicant respectfully traverses the objection and submits that the drawings indeed show every feature of the invention specified in the claims. In particular, Applicant respectfully submits that 37 C.F.R. 1.83(a) specifies that "conventional features disclosed in the description and claims, where the detailed illustration is not essential for proper understanding the invention, should be illustrated in a drawing in the form of graphical drawings some that are labeled representation." Applicant respectfully submits that Figures 3-7 and the accompanying description indeed fully describe the fuzzy logic method of tuning a tunable RF device in the method of tuning an RF impedance matching network. In review of the forgoing, Applicant respectfully requests withdraw of the objection.

SUBMISSION OF RIBBONED COPY OF THE SUBJECT PATENT

The Examiner noticed that the original ribboned copy of U.S. patent No. 5,842,154 has not yet been surrendered by the Applicant. Applicant respectfully submits that such a render will occur in due course.

CERTIFICATE OF CORRECTION

The Examiner objected to the specification noting that a certificate of correction was granted to change the original patent and such changes were not properly entered into the reissue application as though part of the original patent. Applicant has included herewith substitute pages having corrected columns 3 and 5 for insertion in the specification. The replacement sheets include the Certificate of Correction changes made in the application without using underlining or brackets.

In view of the submission of the substitute pages, Applicant respectfully requests withdrawal of this rejection.

OBJECTION TO THE CLAIMS

The Examiner objected to Claims 5 and 6 under 37 C.F.R. 1.75(i). Applicant has amended Claims 5 and 6 according to the Examiner's requirement.

The Examiner objected to Claims 1-37 under 37 C.F.R. 1.75(a) for failing to particularly point out and distinctly claim the subject matter which the Applicant regards as the invention.

Applicant has amended several of the claims and has adopted several of the Examiner's suggestions. Regarding the Examiner's objections to claim 9, the last

two lines regarding "the load impedance", Applicant respectfully submits that ample antecedent basis exists for the term load impedance. Applicant can find no reason why every modifier, i.e. "variable", need be included throughout the claim. In the alternative, Applicant respectfully requests the Examiner to cite relevant passages of MPEP that supports such a requirement. Applicant respectfully submits the same arguments with respect to objections raised by the Examiner at Claim 16, lines 9-10 and 13-14.

Accordingly, Applicant respectfully requests withdrawal of the objections to the claims.

REJECTION UNDER 35 U.S.C. § 112

Claims 31-37 stand rejected under 35 U.S.C. § 112, second paragraph, as being incomplete for omitting essential steps, such omission amounting to a gap between the steps. This rejection is respectfully traversed.

Applicant has amended Claim 31 to eliminate the gap between the steps. Applicant believes this renders the stated grounds for rejection moot.

REJECTION UNDER 35 U.S.C. § 251

Claims 9-37 stand rejected under 35 U.S.C. § 251 as being an improper recapture of broadened claimed subject matter surrendered in the application for the patent upon which the present reissue is based. This rejection is respectfully traversed.

Applicant has amended Claims 9, 16, 24, and 31 in response to the rejections. Applicant believes Claims 9-37 now include the claim limitations identified in the Reasons for Allowance in U.S. application serial no. 08/929,870.

REJECTION UNDER 35 U.S.C. § 103

Claims 31-35 stand rejected under 35 U.S.C. § 103(a) as being unpatentable over Williams (U.S. Pat. No. 5,889,252) in view of Travaglia (U.S. Pat. No. 5,805,649). This rejection is respectfully traversed.

With respect to Claim 31, Williams does not teach or suggest generating a control signal to adjust the variable impedance of a matching network by applying fuzzy logic rules to a sensed signal to generate a fuzzy output value. Williams uses a transformer in the impedance transformation.

The fuzzy logic approach of the present invention uses fuzzy logic rules to improve orthogonality. When there is more than one error signal, the signals are combined. Therefore, the fuzzy logic approach may use any matching network topology.

Travaglia does not teach or suggest using a fuzzy output value for control. Travaglia at best discusses a controller output based on the sum of the phase error and the fuzzy output. Travaglia also does not teach or suggest adjusting the variable impedance of a matching network to match the impedance of a source and load. Travaglia at best discusses a controller that changes an oscillator frequency until its frequency equals that of a reference frequency to achieve phase lock.

Claims 34-37 depend directly from Claim 31 and are allowable for the same reasons.

CONCLUSION

It is believed that all of the stated grounds of rejection have been properly traversed, accommodated, or rendered moot. Applicant therefore respectfully requests that the Examiner reconsider and withdraw all presently outstanding rejections. It is believed that a full and complete response has been made to the outstanding Office Action, and as such, the present application is in condition for allowance. Thus, prompt and favorable consideration of this amendment is respectfully requested. If the Examiner believes that personal communication will expedite prosecution of this application, the Examiner is invited to telephone the undersigned at (248) 641-1600.

Respectfully submitted,

Dated: Dec 12, 2001

By: ____________________
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ATTACHMENT FOR CLAIM AMENDMENTS

The following is a marked up version of each amended claim in which underlines indicates insertions and strikethroughs indicate deletions.

1. (AMENDED) Fuzzy logic method of tuning ~~an~~ a radio frequency (RF) matching network of the type having an input at which is applied RF power at a given frequency and at a given impedance, and an output which applies said power to an RF load having a non-constant impedance, said matching network including a phase-magnitude error detector means providing a phase error signal and a magnitude error signal related respectively to impedance phase angle error and impedance magnitude error, and said matching network comprising at least a first variable impedance having a driven element for varying the impedance thereof and a second variable impedance having a driven element for varying the impedance thereof; the method comprising:

supplying said phase and said magnitude error signals to a fuzzy logic controller, wherein each said error signal has a magnitude and direction,

applying each said phase and magnitude error signal to a fuzzy logic inference function based on a number of overlapping fuzzy sets, and where a ~~the~~ value of each said phase and magnitude error signal enjoys membership in one or more fuzzy sets;

applying fuzzy logic rules to said phase and magnitude error signals according to ~~the~~ said one or more fuzzy sets for which said ~~first and second~~ phase and magnitude error signals enjoy membership;

obtaining drive signal values based on said fuzzy logic rules for each of said phase and magnitude error signals;

weighting said drive signal values according to the respective one or more fuzzy sets inference ~~functions~~ for which said phase and magnitude error signals enjoy membership; and

combining said weighted drive signal values to produce an output drive signal for said first variable impedance device driven element.

2. (AMENDED) Fuzzy logic method of tuning an RF matching network according to claim 1, further comprising

obtaining additional drive signal values based on additional fuzzy logic rules for each of said first and second error signals;

weighting said additional drive signal values according to additional respective fuzzy inference functions; and

combining said ~~such~~ weighted additional drive signal values to produce an output drive signal for said second variable impedance device driven element.

3. (AMENDED) Fuzzy logic method of tuning an RF matching network according to claim 2, wherein said fuzzy logic rules and said additional fuzzy logic rules comprise a matrix of NxM drive signal values, where N is the number of fuzzy sets of

said phase error signal and M is the number of fuzzy sets of said magnitude error signal, and each of said drive signal ~~value~~ values and said additional drive signal values corresponds to a given set of said phase error signal and a given set of said magnitude error signal.

4. (AMENDED) Fuzzy logic method of tuning an RF matching network according to claim 1, said number of overlapping fuzzy sets being centered respectively about zero, a medium positive value, a medium negative value, a high positive value, and a high negative value.

5. (AMENDED) A fuzzy logic controller for tuning an RF matching network, wherein said matching network is positioned between a source of applied RF power at a given frequency and at a given impedance, and an RF load having a non-constant impedance, said matching network including a phase-magnitude error detector means providing a phase error signal and a magnitude error signal related respectively to impedance phase angle error and impedance magnitude error, and said matching network comprising at least a first variable impedance device having a driven element for varying the impedance thereof and a second variable impedance device having a driven element for varying the impedance thereof; the fuzzy logic controller comprising

input means receiving values of said phase and magnitude error signals;

means for applying the values of said phase and magnitude error signals to a fuzzy logic inference function based on a number of overlapping fuzzy sets, and

where a ~~the values~~ value of each said phase and magnitude error ~~signals enjoy~~ signal enjoys membership in one or more fuzzy sets;

means for applying fuzzy logic rules to said phase and magnitude error signals according to fuzzy sets for which said error signals enjoy membership;

means for obtaining drive signal values according to said fuzzy logic rules for each ~~set~~ of said fuzzy sets for which said error signals enjoy membership;

means for weighting said drive signal values according to the respective fuzzy inference functions for the values of said phase and magnitude error signals; and

means for combining said weighted drive signal values to produce an output drive signal for said first variable impedance device driven element.

6. (AMENDED) Fuzzy logic controller according to claim 5, further comprising

means for obtaining additional drive signal values based on additional fuzzy logic rules for each of said phase and magnitude error signals;

means for weighting said additional drive signal values according to additional respective fuzzy inference functions; and

means for combining ~~such~~ weighted said additional drive signal values to produce an output drive signal for said second variable impedance device driven element.

7. (AMENDED) Fuzzy logic method of tuning a tunable RF device of the type having an input at which is applied RF power at a given frequency and at a

given impedance, and an output, including an error detector means providing a first error signal and a second error signal, and said tunable RF ~~means~~ device including at least a first variable impedance having a driven element for varying the impedance thereof and a second variable impedance having a driven element for varying the impedance thereof; the method comprising:

supplying said first and said second error signals to a fuzzy logic controller, wherein each of said first and said second error signal has a magnitude and direction,

applying each of said first and said second error signal to a fuzzy logic inference function based on a number of overlapping fuzzy sets, and generating a membership value that corresponds to ~~the~~ an amount of overlapping membership of the error signal value in one or more fuzzy sets;

applying a plurality of fuzzy logic rules to said first and second error signals according to the fuzzy sets for which said first and second error signals enjoy membership;

obtaining a plurality of drive signal values based on said plurality of fuzzy logic rules for each of said first and second error signals;

weighting said drive signal values according to the respective membership values for said first and second error signals; and

combining said weighted drive signal values to produce an output drive signal for said first variable impedance having said first variable impedance device driven element.

8. (AMENDED) Fuzzy logic method of tuning a tunable RF device according to claim 7, further comprising

obtaining a plurality of additional drive signal values based on additional fuzzy logic rules for each of said first and second error signals;

weighting said additional drive signal values according to a plurality of additional respective fuzzy inference functions; and

combining such weighted additional drive signal values to produce an output drive signal for said second variable impedance device driven element.

9. (AMENDED) An electrical network comprising:

a radio frequency (RF) generator for generating an RF signal, the RF generator having a source impedance;

a load receiving the RF signal, the RF signal providing a driving energy to the load, the load having a variable load impedance;

a matching network interposed between the RF generator and the load, the matching network having a variable network impedance, the matching network detecting at least one of ~~a~~ an impedance phase and an impedance magnitude error and generating at least one of a respective ~~corresponding~~ phase error signal and a magnitude error signal, the matching network varying at least one of the impedance phase and the impedance magnitude error in order to vary the network impedance;

a fuzzy inference module receiving the at least one of the restrictive phase and magnitude error signals and defining a membership value that varies in accordance with membership in at least one fuzzy set; and

a controller receiving the at least one respective phase error signal and magnitude error signal, the controller applying the fuzzy logic rules to the at least one of the respective impedance phase error signal and the impedance magnitude error signal according to the fuzzy sets for which said restrictive error signals enjoy membership in order to generate at least one control signal to vary the network impedance, ~~thereby~~ matching the source impedance and the load impedance~~;~~.

11. (AMENDED) The network of claim ~~10~~ 9 wherein the controller further comprises a rules module having a set of rules applied in accordance with the membership value~~s~~, the rules module generating at least one fuzzy output.

12. (AMENDED) The network of claim ~~11~~ 10 wherein the controller further comprises a defuzzification module, the defuzzification module converting the at least one fuzzy output to the at least one control signal.

16. (AMENDED) An electrical network comprising:

a radio frequency (RF) generator for generating an RF signal, the RF generator having a source impedance,

a load receiving the RF signal, the RF signal providing a driving energy to the load, the load having a variable load impedance;

a matching network interposed between the RF generator and the load, the matching network having a variable network impedance, the matching network detecting at least one network parameter and generating at least one sensed signal, the

matching network varying the network impedance in order to match the variable load impedance and the source impedance, wherein the at least one sensed signal comprises at least one of an impedance phase error signal and an impedance magnitude error signal;

a fuzzy inference module receiving the at least one sensed signal and defining a membership value that varies in accordance with membership in at least one fuzzy set; and

a controller receiving the at least one sensed signal, the controller applying fuzzy logic rules to the at least one sensed signal according to the fuzzy sets for which said first and second error signals enjoy membership in order to generate at least one control signal to vary the network impedance, ~~thereby~~ matching the source impedance and the load impedance~~;~~.

18. (AMENDED) The network of claim ~~17~~ 16 wherein the controller further comprises a rules module having a set of rules applied in accordance with the membership value~~s~~, the rules module generating at least one fuzzy output.

19. (AMENDED) The network of claim ~~18~~ 16 wherein the controller further comprises a defuzzification module, the defuzzification module converting the at least one fuzzy output to the at least one control signal.

23. (AMENDED) The network of claim ~~9~~ 16 wherein the load is a RF plasma chamber.

24. (AMENDED) A method of tuning ~~an~~ a radio frequency (RF) impedance matching network having an input which receives RF power and an output which applies the power to a RF load, the matching network having a variable impedance, comprising the steps of:

determining ~~a~~ an impedance phase error and ~~a~~ an impedance magnitude error and generating a corresponding phase error signal and a corresponding magnitude error signal;

applying the phase impedance and magnitude impedance error signals to a fuzzy logic inference function, the phase and magnitude error signals each having at least one respective membership value in at least one fuzzy set; and

applying fuzzy logic rules to the impedance phase and impedance magnitude error signals according to the fuzzy sets for which said error signals enjoy membership to generate fuzzy output signals based upon the phase and the magnitude error signals and generating a control signal to adjust the variable impedance of the matching network~~;~~.

26. (AMENDED) The method of claim ~~25~~ 24 wherein the step of applying fuzzy logic further comprises applying logic rules to the at least one respective membership value to generate at least one respective fuzzy output value.

27. (AMENDED) The method of claim ~~26~~ 24 wherein the step of applying logic rules further comprises the step of weighting the at least one respective fuzzy output value according to the at least one respective membership value.

28. (AMENDED) The method of claim 27 wherein the step of applying ~~fuzzy~~ logic rules further comprises the step of combining said weighted at least one respective fuzzy output values to produce the control signal.

29. (AMENDED) The method of claim ~~26~~ 24, wherein the ~~fuzzy~~ logic rules comprise a matrix of NxM fuzzy output values, where N is the number of fuzzy sets of a first sensed signal and M is the number of fuzzy sets of a second sensed signal, and each fuzzy output value corresponds to a predetermined set of the first sensed signal and a predetermined set of the second sensed signal.

30. (AMENDED) The method of claim ~~25~~ 24 wherein the at least one fuzzy set comprises a plurality of fuzzy sets centered respectively about zero, a medium positive value, a medium negative value, a high positive value, and a high negative value.

31. (AMENDED) A method of tuning ~~an~~ a radio frequency (RF) impedance matching network having an input which receives RF power and an output which applies the power to a RF load, the matching network having a variable impedance, comprising the steps of:

determining a network parameter and generating a corresponding sensed signal that varies in accordance with the network parameter;

applying the corresponding sensed signal to a fuzzy logic inference function, the corresponding sensed signal having at least one respective membership value in at least one fuzzy set; and

applying fuzzy logic rules to the corresponding sensed signal according to fuzzy sets for which said error signal enjoys membership;

generating fuzzy output signals based upon the corresponding sensed signal; and

generating a control signal to adjust the variable impedance of the matching network based upon the fuzzy output signals.

33. (AMENDED) The method of claim 31 ~~32~~ wherein the step of applying fuzzy logic further comprises applying logic rules to the at least one respective membership value to generate at least one respective fuzzy output value.

34. (AMENDED) The method of claim ~~33~~ 31 wherein the step of applying logic rules further comprises the step of weighting the at least one respective fuzzy output value according to the at least one respective membership value.

35. (AMENDED) The method of claim 34 wherein the step of applying ~~fuzzy~~ logic rules further comprises the step of combining said weighted at least one respective fuzzy output values to produce the control signal.

36. (AMENDED) The method of claim ~~33~~ 31, wherein the ~~fuzzy~~ logic rules comprise a matrix of NxM fuzzy output values, where N is the number of fuzzy sets of the corresponding sensed signal and M is the number of fuzzy sets of a second sensed signal, and each fuzzy output value corresponds to a predetermined set of the ~~first~~ sensed signal and a predetermined set of the second sensed signal.

37. (AMENDED) The method of claim ~~32~~ 31 wherein the at least one fuzzy set comprises a plurality of fuzzy sets centered respectively about zero, a medium positive value, a medium negative value, a high positive value, and a high negative value.

According to an aspect of this invention, a fuzzy logic method is employed for tuning an RF matching network of the type having an input at which is applied RF power at a given frequency and at a given impedance, and an output which applies such power to an RF load having a non-constant impedance, such as an RF plasma chamber. The matching network has a phase-magnitude error detector providing a phase error signal and a magnitude error signal related respectively to the differences between nominal and actual input phase angle, i.e., $\Delta\phi$ and between nominal and actual impedance ΔZ. The matching network has at least a first variable impedance having a driven element for varying its impedance, and a second variable impedance having a driven element for varying its impedance. The fuzzy logic control technique involves the steps of supplying the phase and the magnitude error signals to a fuzzy logic controller, wherein each error signal has a magnitude and direction. Then the error signals are each applied to a fuzzy logic inference function based on membership in one or more fuzzy sets, which may be overlapping fuzzy sets. The value, i.e., the size and direction of each error signal enjoys membership in one, two, or more overlapping fuzzy sets. Fuzzy logic rules are applied to the phase and magnitude error signals according to the fuzzy sets for which said first and second error signals enjoy membership. A plurality of drive signal values are obtained, based on the fuzzy logic rules for each of the phase and magnitude error signals. The drive signal values are weighted according to respective fuzzy inference functions for which the error signals enjoy membership. Then the weighted drive signal values are combined to produce an output drive signal for the first variable impedance device driven element. A similar process creates an output drive signal for the second variable impedance. According to the fuzzy logic rules, the phase and magnitude error signals are used jointly to obtain each of the output drive signals.

The fuzzy logic rules can be expressed as a matrix of N×M drive current values, where N is the number of fuzzy sets of said first error signal and M is the number of fuzzy sets of said second error signal. Here, to obtain each drive current value, there is a given set of rules applying the first error signal and the second error signal.

A fuzzy logic controller is provided according to another aspect of this invention for tuning an RF matching network, wherein the matching network is positioned between a source of applied RF power at a given frequency and at a given impedance, and an RF load, such as an RF plasma chamber, having a non-constant impedance. A phase-magnitude error detector produces a phase error signal and a magnitude error signal related respectively to the phase error and magnitude error in input impedance, as discussed earlier. The matching network also has at least a first variable impedance having a driven element for varying the impedance thereof and a second variable impedance having a driven element for varying the impedance thereof. The fuzzy logic controller has input means to receive the values of the phase and magnitude error signals. The controller applies these values of error signals to a fuzzy logic inference function based on a number of overlapping fuzzy sets. The values of error signals enjoy membership in one, two, or more overlapping fuzzy sets. Fuzzy logic rules are applied to the phase and magnitude error signals, with the rules depending on the fuzzy sets for which the error signals enjoy membership. Drive signal values are obtained according to the fuzzy logic rules for each fuzzy set for which the error signals enjoy membership. The drive signal values are weighted according to the respective fuzzy inference functions for the values of these error signals. Then the weighted drive signal values are combined to produce an output drive signal for the first variable impedance device driven element. Additional drive signal values are obtained based on additional fuzzy logic rules for each of the phase and magnitude error signals. Then these additional drive signal values are weighted according to additional respective fuzzy inference functions, and the weighted drive signal values are combined to produce an output drive signal for the second variable impedance device driven element.

The fuzzy logic controller quickly drives the tuning elements to a matched impedance state, and avoids lost condition problems. The fuzzy logic controller can be implemented in hardware, or can be based on a programmed device such as a digital signal processor (DSP) or a microprocessor. The fuzzy logic controller function can operate in background, or can employ a separate hardware device to free the DSP for other functions such as signal processing, motor control, user interface, or other functions. A separate independent PC can be employed to carry out the fuzzy logic tuning.

Further enhancements in performance can be obtained by employing additional inputs. For example, tuning element positions can be used as inputs to linearize loop gain as a function of position. This can achieve higher overall loop gain and faster tuning speeds. A reduction or elimination of lost conditions can be achieved by using additional sensors, e.g., voltage and current at the RF plasma chamber, and then applying the detected levels as additional inputs to the fuzzy logic controller.

The improvements of this invention use fuzzy logic to provide a practical method to analyze multiple inputs and to produce signals which will drive multiple tuning elements. In a minimal system, the fuzzy controller inputs can consist of phase and magnitude errors, and the fuzzy outputs can consist of one or both of the drive signals for the tuning elements.

The invention can be easily extended to control of three or more variable tuning devices.

The above and many other objects, features, and advantages of this invention will become apparent from the ensuing description of a preferred embodiment, which is to be read in conjunction with the accompanying Drawing.

BRIEF DESCRIPTION OF THE DRAWING

FIG. 1 is a system block diagram of an RF plasma process incorporating an impedance match net with a fuzzy logic control system according to one embodiment of this invention.

FIG. 2 is an enlarged schematic diagram of the match net and control system of this embodiment.

FIGS. 3 and 4 are charts of the fuzzy logic inference functions or membership functions with respect to the fuzzy sets of impedance magnitude error and phase angle error, respectively.

FIGS. 5A and 5B are fuzzy logic rule application matrices for first and second variable impedance tuning drive signals according to an embodiment of this invention.

FIGS. 6A and 6B are fuzzy logic rule application matrices for first and second variable impedance tuning drive signals according to another embodiment of this invention.

FIG. 7 illustrates a three-dimensional fuzzy logic rule application matrix that can be employed with additional embodiments of this invention.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENT

With reference to the Drawing figures, and initially to FIG. 1, an RF plasma processing system 10 is shown for

purposes of example. A plasma generator 12 provides RF electrical power at a predetermined frequency, i.e., 13.56 MHz. The output of the generator 12 is followed by a harmonic/subharmonic filter 14, which is then followed by an impedance matching network 16, which supplies the electrical power through a voltage/current sensor system 18 to an input of a plasma chamber 20. The matching network 16 comprises a controllable impedance matching unit 22, with a phase/magnitude sensor 24 connected at its input. The sensor provides a phase error signal $\Delta\phi$ that is proportional to the difference between the nominal input impedance phase angle and the actual phase angle ($\phi-\phi_O$) of the impedance matching unit, and also provides a magnitude error signal ΔZ that is proportional to the difference between the nominal input impedance and actual input impedance ($Z-Z_O$)

A fuzzy logic controller 26 has inputs to receive the phase error signal $\Delta\phi$ and to receive the magnitude error signal ΔZ, and respective control signal outputs CS1 and CS2 for controlling respective first and second variable impedance devices within the unit 22. An optional third control signal output CS3 is shown in ghost lines. Additional sensors 28 can optionally provide the fuzzy logic controller 26 with additional input signals, e.g., time rate of change of phase error. The fuzzy logic controller can be a separate unit, but may also be incorporated into the housing of the impedance matching network 16. The operating codes, including the fuzzy logic rule matrix and fuzzy logic inference function algorithm can be stored in a memory device (not shown) of the controller 26. This memory device can be a programmable read-only memory, such as an E-PROM, capable of storing downloaded program codes, and providing for revision of the codes to optimize the tuning of the matching network 16. It is also possible to employ a "fixed match" arrangement, and use the error signals $\Delta\phi$ and ΔZ to control the frequency of the plasma generator 12.

FIG. 2 shows details of the match net unit 22 and the fuzzy logic controller 26 from which for the operation of this invention can be explained. The match net unit 22 includes a number of variable impedance devices for effecting tuning to establish an impedance match between the 50 ohms of the RF generator 12 and the unknown impedance of the RF plasma chamber 20. Besides the fixed impedances (not shown) there can be a first tuning capacitor C1 and a second capacitor C2. Optionally, there can also be a third tuning capacitor C3 and/or a tunable inductor L. The first and second tuning capacitors each have a tuning element motor M1 and M2, respectively. If additional tuning elements are desired, a third tuning element motor M3 can be provided for the third capacitor C3. Also, a motor (not shown) can be provided for the tuning slug of the tunable inductor L.

The fuzzy logic controller 26 here accomplishes three operations on the input signals, which are here shown as the phase error signal $\Delta\phi$, the impedance magnitude error signal ΔZ, and any additional error signals, e.g., from other sensors 28. The error signals are first applied to a fuzzification stage 29, where the error signals are applied to respective fuzzy inference functions 30, 32, 34. These functions here are shown as sequences of overlapping triangular or trapezoidal ramp functions, and will be explained in detail shortly. Then, in a rule evaluation stage 35, predetermined rules are applied, depending on the fuzzy sets in the fuzzification stage 29 to which each of the error signals enjoys membership. These can be expressed as IF-AND-THEN logic statements, such as IF the phase error is negative and large, AND IF the magnitude error is positive and medium, THEN apply a positive large drive signal as CS1 and apply a negative medium drive signal as CS2. The rules for all combinations of fuzzy set memberships of phase error and magnitude error can be considered as a matrix of N×M rules, where N is the number of fuzzy sets of phase error and M is the number of fuzzy sets of magnitude error. The several drive signal values obtained in the rule evaluation stage 35 are then converted to discrete drive signal values CS1, CS2, CS3, etc., in a defuzzification stage 37.

In the fuzzification stage 29, ramp-shaped membership functions, or fuzzy inference functions 32 and 30 are employed, as shown in FIGS. 3 and 4, respectively for the impedance magnitude error ΔZ, and for the phase error $\Delta\phi$. These are overlapping functions, as shown, so that the respective error signal values are partly members of one fuzzy set and also partly members of an overlapping fuzzy set. In the example shown here in FIG. 3, the magnitude error ΔZ is of a positive value, and has a membership of 35% of zero error, and 65% positive medium error. At the same time, as shown in FIG. 4, the phase error $\Delta\phi$ has a negative value, and enjoys a 25% membership in the zero error fuzzy set and a 75% membership in the negative medium fuzzy set. These membership values are used for weighting and combining the respective drive signal values that are obtained according to the fuzzy rules application stage 35.

In the defuzzification stage 37, a weighting factor is applied to the drive signal values that are obtained, based on the conditions of magnitude error positive medium, phase error negative medium; magnitude error positive medium, phase error zero; magnitude error zero, phase error negative medium; and magnitude error zero, phase error zero (for the example in FIGS. 3 and 4). These are weighted according to their respective membership values, and are combined for each drive signal CS1, CS2, CS3, etc. This results in bringing each of the tuning devices quickly to a tuned condition, and accounts for the effect of each device on the phase error and magnitude error signals. The amount of movement for each tuning device also depends on the size and sign (positive or negative) of the phase and magnitude error. Thus, this system avoids the major pitfalls of prior art impedance match networks, as mentioned previously.

FIGS. 5A and 5B are matrices of typical fuzzy logic rules for a given impedance match network. Here, the notation used in the grid squares indicates the size and direction of motor current to be applied to the first tuning capacitor (FIG. 5A) and to be applied to the second tuning capacitor (FIG. 5B). These are PL—positive large; PM—positive medium; Ze—zero; NM—negative medium; and NL—negative large. The labels on the vertical and horizontal axes represent the fuzzy sets for the magnitude error and phase error, namely NL—negative large; NM—negative medium; Ze—zero; PM—positive medium; and PL—positive large. As is apparent, these matrices are somewhat asymmetric or unbalanced, as they have to account for the problems of non-linearity, cross-over, and lost conditions, as mentioned before. These matrices can be arrived at rather quickly by the process engineer, starting with orthogonal or symmetric matrices, where the drive current values depend on only one error signal. A pair of orthogonal matrices are shown in FIGS. 6A and 6B. Based on the engineer's experience and by making intuitive adjustments to the matrix, in particular at the conditions where cross-over and lost conditions may be likely to occur, the process engineer can try modified rule sets against a synthetic load. By obtaining the results of the tuning algorithm the matrices can be changed incrementally, as need be, for each iteration. Within a reasonable number of trials, the process engineer will arrive at an optimal pair of rule set matrices, like those of FIGS. 5A and 5B.